NOTES

1. Papers selected for inclusion in General Sessions will be available at the Conference in the following official languages of the United Nations: English, French, Russian and Spanish.

2. Papers selected for inclusion in Specialized Sessions will be available at the Conference in only one of the above official languages.

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AEROGEOPHYSICS AND ITS ROLE IN MINERAL EXPLORATION

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1. Introduction

(a) In trying to foster exploration and assess possibilities of mineral occurrences in areas in which there has been little or no prospecting and where geological information is sparse, governments are faced with the decision of whether or not to sponsor apparently expensive aerogeophysical surveys. The methods are powerful but they do not stand alone. It is not enough to sponsor aeromagnetic or airborne E.M. surveys, thinking that by so doing potential mines are pinpointed. Aerogeophysical surveys do not find mines, they find anomalies on which extensive ground follow-up work of several kinds must be performed before they can be considered worth drilling. A very small percentage of interesting anomalies actually become producing mines. Governments sponsoring aerogeophysical surveys should, therefore, regard such surveys as only small, but important links in the process of finding and proving ore. Provision should be made for all the other associated costly work which should come both before and after such surveys.

(b) In an attempt to view aerogeophysical surveys in their correct sequence and cost setting relative to the other associated exploratory work, Table 1 is presented as an exploration program of the type undertaken[a] by the larger Canadian mining companies operating in Canada. This program is oriented towards exploration for metallic sulphide and magnetic iron deposits because it is these types of deposits which are most susceptible to aerogeophysical methods. In prospecting for other minerals, there would therefore be less emphasis on aerogeophysics. By exploration, in this paper, is meant work directed towards the discovery of orebodies not immediately associated with known productive deposits. There will, no doubt, be wide differences of opinion not only about the details of the program in Table 1, but indeed about the wisdom of the whole concept. It serves its purpose in this paper, however, merely by providing a basis for discussion.

2. Explanation of Table 1

(a) In the construction of Table 1, the job of systematically exploring a 5000 square mile area is envisaged. This is about the minimum-sized block to which such a comprehensive program could be efficiently applied. The work is subdivided into 13 steps, each step representing a different type of work. The program could be completed in two or three years or stretched over a longer period.

(b) The main purpose of this table and in fact of the paper is to point out that in an integrated program of this nature, all the steps should be performed in a planned sequence, so that the results of one step may be used in performing the next. Lack of planning can often result in devastating loss of efficiency. Furthermore, no one step should be undertaken without having made provision for the steps to follow. Although such work would not be wasted, it would mean that money would be tied up needlessly. This is a common mistake in the mineral exploration programs of both private companies and governments.

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[a] Most of the work up to step 9, at least, is presently being done by the federal and provincial governments in Canada.

(c) In broad terms, the program is designed to begin with the less costly and less detailed investigations. The first major commitment to systematic exploration takes place at step 7 and if the decision is made to go ahead, plans and provision should be made to ensure that the program will be completed. There is no major commitment to the end of step 6 because if planimetric maps are not used for mineral exploration, they can be used for many other purposes. It should be noticed that there is no narrowing down of the size of the area until step 10, the geological mapping at a scale of 1/50,000. Judicious choice should be made at this point to select the most promising areas. This is where the second major commitment is made since the cost jumps to a minimum of about $30 per square mile. However, this work and the work which precedes it is basic scientific information which is good for all time and can be used for any future exploration. It is for this reason that many governments (including the Canadian government) carry the work to the end of step 10 at public expense and leave further, more financially risky work to private enterprise.

(d) The final detailed part of the program from step 11 to step 13 has been termed "saturation prospecting"[b]. If no mineral deposits are found as a result of applying such a procedure, it does not mean that no deposits exist in the area, it simply means that every known method has been applied and that further exploration money might better be spent elsewhere (or not at all). It is at stage 11 where the decision maker must exercise his most critical judgment. Not only must he select the area for intensive investigation, he must also decide on whether or not to use airborne E.M. and if so, what kind he should use, because there are at least 15 different instruments available and all have different capabilities in different situations. Similarly at step 12 in ground geophysical follow-up work, he must select the type of survey that has the best chance of verifying or modifying his conclusions. His most critical selection, however, is that of the location for diamond drilling, for at this point the whole program is successfully, or unsuccessfully, concluded.

(e) Another and perhaps the most important aspect of the principle of beginning with the less costly procedures, is that the easily-found mines may be discovered in the early stages so that discovery costs would be reduced.

(f) The reason 1/50,000 aeromagnetic mapping is placed before 1/250,000 geological mapping is that the results of the aeromagnetic survey can be used to great advantage in interpreting the geology at 1/250,000, as well as being used later to aid the 1/50,000 geological mapping.

(g) The location of magnetic iron deposits, if any exist in the area, takes place as a direct and automatic result of the 1/50,000 aeromagnetic surveying. But while the finding may be much less costly than for base-metal deposits, the problems of the nature of the ore, its grade, means of transportation and markets are much more critical.

(h) The cost of aerogeophysical surveys is less per line mile for large blocks. Savings in this respect reach a maximum at about 30,000 line miles depending upon the distance the aircraft is being operated from its home base. If work planned is less than this mileage for a single job, it is worthwhile attempting to share an aircraft with another organization or country working nearby. Another way of reducing costs is to combine an aeromagnetic survey with an airphoto survey. When the cloud ceiling is not high enough for aerial photography, the aircraft can be used for low-level aeromagnetic work. Planimetric maps made from the airphotos are not required until compilation of the aeromagnetic maps is started. Aeromagnetic flying can be done directly from airphotos.

(i) Planimetric maps and preferably controlled mosaics constructed from these maps should be made prior to compilation in systematic aeromagnetic mapping at a scale of 1/50,000. It is possible to work directly from aerial photographs or use uncontrolled mosaics as base maps, but such procedure invariably leads to later difficulties often involving complete recompilation of geophysical data when proper maps do become

[b] Symposium on Saturation Prospecting, Canadian Mining and Metallurgical Bull. Jan. 1959.

available. The cost of such maps should not be charged against mineral exploration alone, because such maps find extensive use in dozens of other fields.

(j) Aerogeophysical surveys can be made for certain purposes using electronic navigation without the use of airphotos or planimetric maps. Electronic navigation may be adequate for oil surveys where anomaly sources are buried perhaps 5000 feet, but in mineral surveys anomalies must be accurately located with respect to nearby geographical features. To accomplish this properly planimetric maps or photo mosaics should be used.

3. The role of the prospector

(a) Is it necessary to spend so much money to find mines? Throughout history, and even today, prospectors find mines with few aids and much smaller budgets. However, in areas where surface prospecting has been done for many years, a prospector's chances of success are poor because surface showings have long since been investigated. This is seldom the case, however, in mountainous areas, which are not as readily accessible. Because of their high relief, combined often with heavy tree-cover, there are usually many more hidden outcrops than in comparable areas of low relief. Furthermore, aerogeophysical methods are not as effective in mountainous terrain as in terrain of low relief, because it is not possible to fly close to the ground - a necessary procedure in aerogeophysical prospecting.

(b) Modern prospectors, like their old-time counterparts, possess an important characteristic. They know what they are looking for and are not side-tracked by scientifically interesting rock formations and geophysical or geochemical theories and instruments. Yet they are efficient in the use of airphotos, have adequate knowledge of geology, can use simple geophysical instruments and are familiar with simple geochemical testing procedures. Thus, in unprospected areas with good rock exposures, the cheapest way to find a mine is to encourage surface prospectors. On the other hand, in well-prospected areas, the only way to make discoveries is by use of modern methods. Step number A is inserted in the table conditional upon whether or not the area has been previously prospected on surface. If undertaken, such a program should run parallel to the main program in Table 1. The cost of $20,000 per year is, of course, dependent upon terms granted the prospectors. Many prefer to receive nominal wages with a chance to share in the profits of a discovery.

4. Description of aerogeophysical methods

Aerogeophysical methods and their underlying principles, instruments and survey procedures have been abundantly described. Table 2 gives a brief resume of the three methods.

5. Organization and Training of Personnel

No facilities exist for the training of personnel in the operation, compilation and interpretation of aerogeophysical surveys although it has been suggested that a training centre be set up under the auspices of the United Nations[c]. At present, the only way of training personnel is to purchase equipment and to employ specialists from aerial survey companies or through the United Nations to instruct these personnel. A man with university training in geophysics should be put in overall charge of an aerogeophysical unit. An electronic engineer or well-trained technician should be employed to supervise the installation and maintenance of the instruments. He can in turn instruct less-qualified technicians in the operation and maintenance of the equipment. Whether the unit is operated under the administrative authority of a geological organization or not, certainly it is a geological organization which should be responsible for planning the work of a unit and integrating it into an overall mineral exploration program. Whether or not it is worthwhile for a country to set up its own aerogeophysical facility for mineral exploration depends upon the size of the mineral potential areas. It would not seem worthwhile for a government to do this unless there were at least 10 years of continuous work for the unit to perform. This would correspond to an area of at least 100,000 square miles.

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[c]United Nations: Proceedings of the United Nations Seminar on Aerial Survey Methods and Equipments, Mineral Resources Development Series No. 12, p. 16, 1960.

TABLE I. A HYPOTHETICAL MINERAL EXPLORATION PROGRAM FOR AN UNEXPLORED AREA OF 5,000 SQUARE MILES

(oriented towards metallic sulphide and magnetic iron deposits)

PHASE	STEP NO.	TYPE OF WORK	AREA (Sq. Mi.)	COST Thousands Can. $	COST Per Sq. Mi. Can. $	PURPOSE OF WORK
PARALLEL PROGRAM	A	GROUND PROSPECTING	5,000	10 - 20 per year	2.00 - 4.00	To locate surface showings in areas of outcrop. Should be run parallel to main program.
BROAD	1	AEROMAGNETIC RECONNAISSANCE	5,000	2 - 3	0.40 - 0.60	To determine extent of area covered by igneous and metamorphic rocks and to delineate sedimentary basins and broad formations of volcanic and ultrabasic rocks.
RECONNAISSANCE	2	BROAD GEOLOGICAL RECONNAISSANCE	5,000	10 - 20	2.00 - 4.00	To map rock types along easily accessible routes such as roads, rivers and lakeshores.
SYSTEMATIC PLANIMETRIC MAPPING	3	AERIAL PHOTOGRAPHY 1/50,000	5,000	20 - 30	4.00 - 6.00	This phase should not be charged against mineral exploration alone since the maps will be used for development planning and several other types of resource surveys. (Many governments proceed directly to the construction of topographic maps without making less costly planimetric maps first.)
	4	GROUND CONTROL	5,000	10 - 15	2.00 - 3.00	
	5	PLANIMETRIC COMPILATION 1/50,000	5,000	10 - 15	2.00 - 3.00	
	6	CONTROLLED MOSAICS 1/50,000	5,000	2 - 3	0.40 - 0.60	
SYSTEMATIC AEROGEOPHYSICAL	7	AEROMAGNETIC MAPPING 1/2 mile spacing, 1,000' elev.	5,000	50 - 75	10.00 - 15.00	To aid geological mapping by tracing hidden contacts of rock formations of contrasting magnetic properties and to locate magnetic iron deposits
	8	RECONNAISSANCE GEOLOGICAL MAPPING - 1/250,000	5,000	25 - 30	5.00 - 7.00	To map groups of rock formations and geologic structure thus providing clues to the location of ore deposits.
GEOCHEMICAL AND GEOLOGICAL MAPPING	9	GEOCHEMICAL RECONNAISSANCE 1/250,000	5,000	20 - 30	4.00 - 6.00	To chemically analyse stream sediments, surface waters and rock samples for Cu, Pb, Zn content thus delineating most likely areas for deposits.
	10	GEOLOGICAL MAPPING 1/50,000	600	18 - 70	30.00 - 117.00	Same as (8) except subdividing mapped groups further and showing more detailed structure.
DETAILED EXPLORATION	11	DETAILED AEROMAGNETIC AND ELECTROMAGNETIC 1/8 mile spacing 300' elev.	150	40 - 60	266.00 - 400.00	Detailed mapping of magnetics and searching for conductor systems. Such anomalies could be caused by metallic sulphide deposits.
	12	GEOPHYSICAL GROUND FOLLOW-UP	50	40 - 60	800.00 - 1,200.00	Verifying existence and exact location of airborne anomalies on ground and to measure anomalies by other geophysical methods.
	13	DETAILED GEOLOGICAL MAPPING, GEOCHEMICAL TESTING, EXPLORATORY DRILLING	50	300 - 400	6,000.00 - 8,000.00	Mapping detailed geological structure in order to determine best drill location and angle of holes. Geochemical testing to check anomaly is caused by metal deposit.
POST-PROGRAM	Z	DRILLING TO PROVE UP OREBODY		?	—	

TABLE 2. SUMMARY OF AEROGEOPHYSICAL METHODS

METHOD	ROCK PROPERTY MEASURED	DIRECT INDICATION OF (direct prospecting)	VALUE AS AID TO GEOLOGICAL MAPPING (indirect prospecting)	MANY MISLEADING ANOMALIES CAUSED BY	PENETRATION	INSTRUMENTS AVAILABLE COMMERCIALLY	COST OF INSTRUMENTS AND INSTALLATION	NUMBER OF PERSONNEL IN ADDITION TO FLYING CREW
AERO-MAGNETIC	Intensity of magnetization approximately proportional to per cent magnetite in rock	Magnetite deposits. — Pyrrhotite deposits - but may be confused with deposits of disseminated magnetite	Good	Disseminated magnetite and barren pyrrhotite	Unaffected by overburden, but poor through thick lava flows	Fluxgate - no Proton - yes	$30,000 - $50,000	1 geophysicist 1 electronic technician 2 operators 10 compilers
AERO-ELECTRIC	Electrical conductivity mostly caused by sulphides of iron, copper and lead and by graphite	Massive metallic sulphide deposits	Poor	Barren metallic sulphides. Abundant graphite occurrences. Saline overburden	0 - 400 ft. decreases with increase in conductivity of overburden	Several	$30,000 - $50,000	1 geophysicist 1 electronic technician 1 operator 2 compilers
AERO-RADIOMETRIC	Natural gamma ray activity of uranium, thorium and potassium-40 on surface of ground	Uranium	Limited (not generally used)	Large outcrops of granite containing disseminated potassium-40, thorium and uranium	Nil — Gamma rays absorbed by water and overburden	Several	$5,000 - $10,000	1 operator 1 compiler

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